The use of context and hierarchies to extend seamlessness into technology choice

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1 Introduction

As our understanding of the underlying behaviour of Nature moves from the laboratory to its application in a technology which is used by humans, then a question arises as how to cope with the overwhelming complexity.

This paper considers the use of context that surrounds each piece of knowledge (such as the constant temperature implicit in many of the constants and coefficients) and how lower level contexts can be held in different hierarchical levels in the manner of an ecologist trying to understand an ecosystem. Using hierarchies to hold the lower level contexts means they remain within scope even if they are not explicit.

The use of hierarchies in this manner is a possible tool (with a slightly different perspective) that could be used to enable the development and use of improved technologies.

2 Overview

All human activities occur within a context. These can be as broad as a particular country with a certain set of environmental, socio-economic and technological conditions. However, the contexts that are of interest in this paper are those that arise from the other end of the spectrum, these contexts arise from the derivational roots that are used to design our technologies. In particular the inherent ability (or lack thereof) of a particular formulation to determine what could be termed the best technology for the task. This intended end-use needs to influence the formulation for it to be most useful.

For many technologies the form of the technology is driven by functionality and commerce. When science is needed to resolve issues a practical form of science is often used as this is easily determined by experimentation and regression analysis. The convenience of using a practical formulation is sufficient for many technological applications. For example, an experimentally determined rate constant based on total volatile solids with a certain mix of faeces, urine and greywater will apply to other sewerage systems so long as the proportions contributing to the mixture are more or less constant. Problems will arise however if the mixture is too different from the original test mixture, as the context has changed beyond its derivational roots. Such a formulation could not be applied separately to each of the three waste streams that constitute sewerage for example.

One solution is to determine a new value for the rate constant for each different mixture and accept that it only applies to the particular mixture with limited application either side of the experimental mixture. The context in this case is very specific.

In contrast to the specific contexts mentioned above, science begins by observing Nature and therefore has no technological context. This absence of any technological context in the fundamental laws and processes is therefore a good place to begin building formulations that apply to a wide set of technologies and enable an interface for human use in technology.

However, each of the fundamental laws and processes that describe Nature applies to only a small part of the complexity, so several of them are required to explain a system which may be embedded in a technology. Consequently, the complexity involved in building formulations of larger systems is considerable. This complexity is both problematic and advantageous. Advantages arise in that different formulations are possible and these can be targeted for end use. The use of finite volume methods enabling variable temperatures to enter the model and the derivation of optimising parameters are examples of this possible specificity. The problem with the complexity arises from both the over-parameterisation that arises as more layers of complexity are involved, and the difficulty in visualising it; in part due to the use of the mathematical version of Nature.

To aid navigation through this complexity, it has been argued elsewhere (Chapman, 2010) that seamlessness is a tool that allows the causation inherent in the underlying laws and processes to be fully represented in the model output. Seamlessness requires that all information can be shown to influence the model output. When applied to any complex system (a composting particle in the case of Chapman (2010)), seamlessness enables identification of the context that applies to each of the parameters in the formulation.

As increasingly complex structures are assembled using the fundamental laws and processes the context changes – the particle context of Chapman (2008) exists within the context of the pile; while the pile exists within the context of the technology etc. The notion of different hierarchical levels as proposed by Grimm et al. (2005) is argued to be useful as a holder of context.

3 Technological Context

Consider the change in context for a composting particle as influenced by its location in the system and the system's purpose:

Table 1

Context	***Significant implicit context parameters***
Particle (Laboratory)	Particle size; O_2 concentration; *constant* temperature.
Particle (real world)	Particle size; O_2 concentration; *changing* temperature.
Pile	Range of particle sizes and types; range of O_2 concentrations; changing temperature.
Technology	Container characteristics; aeration regimes; Desired social goals: -pathogen control -environmental effects
Social system	Different technologies; cost; resource consumption; energy requirement; law etc

Nature ↓

Humans ↑

Note in Table 1 that as the context widens out of the laboratory and is prepared for use in a technology then each of the lower level contexts still exists, a pile is composed of many particles each with its own context. This is in contrast to the social system where particle sizes, types and oxygen concentrations are so far down the list of considerations as to be deemed insignificant. Technologies therefore occupy a special place. Their performance is dependent on the contexts of all parts of Nature that contribute, yet these elements do not exist in the social system considerations. Indeed, it is only if the technology *fails* to perform that consideration of these lower level contexts may occur.

However, a technology's location can be a source of creativity for humans as it straddles the divide between human and Nature. The social/commercial side of this interface is the subject of Chapman (2011) & (2014). In preparation for that role, an adequate description of Nature is required. The challenge for science is to formulate models that retain full expression of the core fundamentals while applying the model in ever widening contexts; the pragmatic application of science.

4 Modelling Context

Each application of the fundamental laws needs the equation to be solved for a set of 'boundary conditions' that is, the formulation is specific to a certain context. For example, Chapman (2008) used a second law of diffusion solution which included: steady-state conditions, unchanging rate constant (constant temperature), and a zero-order oxygen consumption kinetic. Model limits can arise from these boundary conditions, for example Chapman's model needed special consideration to accommodate changing temperatures as the rate constant, diffusion coefficient and the solubility of oxygen in water are all affected by temperature; they become variables when temperature changes, but the mathematical formulation that was used required them to be constant. Yet the fundamental laws and processes still apply to a real-world composting particle, it is our model, our mathematical formulation, which limit the use in wider contexts.

It was argued in Chapman (2010) that identifying the elements that generate the patterns in complex systems is more significant than detail in determining a model's precision. This conclusion arose from the experimental evidence in Chapman (2009) which gave a regression coefficient to data which seemed at odds with the compromises that needed to be made to formulate the model. If the use of patterns is more important than detail then these patterns need closer scrutiny.

Consider the following explanation in terms of identifying the patterns of Chapman's formulation:

- An interaction (in his case: microbial kinetics and diffusion laws).
- A context (microbial degradation of a **particle** in the real-world).
- Necessary input parameters (diffusion coefficient, solubility of oxygen in water, rate constant etc).
- An output generated by the interaction occurring within the context using the necessary input parameters (composting rate of the particle = ∑(micro-environments)).

However, the same form of: an interaction generating emergent properties within a context, can also be applied to Chapman's input parameters. For example, diffusion occurs because molecules vibrate randomly and interact with their neighbour. As a consequence, the chance of them moving into an area of lower density is greater than the chance of movement into a higher density. The net result of this interaction is described by the mathematical formulation of diffusion laws (Fick's law). An interaction (molecular movement and probability), within a context (molecular scale concentration gradients) generating emergent parameters (diffusion) is maintained, even though the context is different to Chapman's composting particle. Move up the scale to the context of the pile and the interaction is the particle composting rate with the pile-air oxygen concentration. The output is the observed composting rate of the pile.

Note with the above example, that as context applies to more complex systems the lower level contexts still exist (Table 1). A pile is the proportionate contribution from each particle that occurs within the pile; consequently the context of the particle exists within the context of the pile.

Context therefore occurs at all levels in the system; contexts within contexts. In this form they are useful for the person understanding the detail of the system, but not very useful for navigating through the complexity of the system. Placing these different contexts into Grimm's notion of hierarchies by contrast is very useful.

5 Hierarchies

Grimm et al.'s hierarchies become a useful holder of the **context**. Widen the context, such as applying diffusion laws to composting, and a new hierarchy is formed. Widen the context still further to involve the technology housing the compost pile and a new hierarchy is formed. Even the sewerage system discussed in Chapman (2014) could be framed in the same ecological language, where the context is three waste streams and a system composed of several technologies and the system needs to serve social requirements.

If all the parts involved in the interaction retain their essential causation by maintaining seamlessness, then this causation would also be retained in the emergent parameters (be it a physical structure or a mathematical variable). This is bottom-up modelling in its elemental form.

Thus:

- The lowest hierarchy level contains the coefficients and constants that science has determined by observing nature and formulating laws that explain their value: diffusion coefficient, solubility of oxygen in water, rate constant. The effect of temperature is not needed as a separate parameter in composting because its influence occurs at this lowest hierarchical level (where it does appear as a parameter). That is: the Arrhenius equation for the temperature effect on the rate constant; Wilke-Chang equation in the case of the diffusion coefficient; tables of observed experimental data for the solubility of oxygen in water etc.
- The next hierarchical level utilises these emergent parameters (D, k, C etc) in the assemblage of the appropriate laws and logic – diffusion laws and microbial kinetics in the case of composting. The emergent parameter from this interaction, oxygen penetration distance (z), occurs within a context which is a certain size (and type) of particle for which oxygen diffuses in from the particle surface.
- A third hierarchical level could be seen as encompassing aerobic proportion. At this level, Φ emerges from the interaction of z with particle size and geometry in the context of the oxygen concentration at the particle surface. What determines the oxygen concentration at the particle surface is a whole sequence of events that now become associated with the value of Φ. Aerobic proportion (Φ) 'contains' the information from both the interaction of the fundamentals (microbial kinetics and diffusion laws that generate z at the second hierarchical level) in addition to all the information inherent in the sequence of events that determine the oxygen concentration throughout the pile. This hierarchical level in composting can be split into two:
    - Particle aerobic proportion, for which the context is specific to a single: oxygen concentration, particle size and type.
    - Pile aerobic proportion, which emerges from a collection of particles in the context of: a range of particle sizes, types, and the oxygen distribution in the pile which

includes the manner in which oxygen enters and is distributed throughout the pile (this includes the technology).

- The fourth hierarchical level in this framework would be the technologies that surround the system.

Using the hierarchical perspective to understand complexity has the effect of 'layering' the complexity into easier to understand parts. This structure is consistent with (indeed emerges from) the underlying processes. It forms a part of the digital-age abacus that was mentioned earlier where the computational power of the structure becomes an important part of the model. The computational units in this analysis are only slightly different from Grimm et al.'s 'agents'. This computational power manifests most strongly if seamlessness plays its part in forming the structure as the fundamental laws and processes then play their appropriate role.

In addition, there are certain behavioural characteristics that 'emerge' when using a hierarchy perspective:

- At each hierarchical level a Medawar optimum will apply. The best formulation is likely to be one which compromises some of the detail, but best reflects the underlying patterns that dominate the hierarchy, yet serves both: the requirements of the next hierarchical level and the boundary conditions of the model.
- As an information carrying structure (emergent parameter) enters the next hierarchical level, the contributing parts that generated it are stripped away (only the value transfers, not the equation(s)). The value of the parameters in the equation(s) that generated the information carrying structure becomes the context for the value. This context is retained, along with its seamlessness (the **net** effect of the interaction of the fundamentals). This occurs for information carrying structures that have either a physical form, such as a micro-environment, or a parameter with a value, such as z, VOR, Φ. The emergence of these information carrying structures and the movement of their contributing parameters into the context at higher hierarchies is a convenient way of dealing with the over-parameterization problem that could emerge from higher hierarchical level calculations. The over-laying, interdependent sets of equations used by Chapman (2009) to determine the parameter values in composting is an example of the usefulness of this structure. A model structure that lends itself to iterative methods, yet replicates the underlying processes in the real-world.
- At each hierarchical level, the 'information transferability' often occurs in only a small zone of the system complexity. Let's call it the Medawar interaction point. The point where the information carrying tasks are achieved. These implicit assumptions of the parameter value (carried in the context), are a 'constraint' that limit the application of the model. For example:
    - The constant temperature at which variables become constants, generating our well known formulations (Fick's law of diffusion, microbial kinetics etc). These useful scientific abstractions only become problematic when applied to the real-world, as temperature is not constant and impacts the lowest level of the hierarchy by invalidating the constant (it becomes a variable). Resolved in Chapman's case by using finite element methods and retaining the constant.
    - The averaging effect of Φ_pile, where the net result of a wide range of site specific composting rates are represented. However, a property of this parameter is that it not only captures a change at any point in the pile (or particle) but also the technology that surrounds the pile (via aeration strategies, impermeable walls etc). Any change will be reflected in the value of Φ and it this change in value which is useful in

facilitating the social interface. In particular, this formulation is more or less synonymous with mathematical optimisation techniques. It becomes useful in this context.

  - All the complexity of multiple combinations of technologies in parallel and series (such as the ‘sewerage’ system discussed in Chapman (2014)) reduces to simplicity when: the number of technologies = 1, the container is cubical, a single electron acceptor is used, and all microbial kinetic parameters are optimised. That is, a ‘standardised’ technology in the case of sewerage systems. Yet the information content in the fundamental equations is retained (any of the contributing technology’s behaviour could be equally easily explained by choosing the relevant parameters).

- Determining a value for an emergent parameter in a higher hierarchical level necessitates a value in all of the parameters that occur in lower level hierarchies. At the instant of calculation, all of the system complexity collapses to a single point in time freezing the conditions at all points in space. This characteristic enabled Chapman to use finite volume methods to incorporate environmental variables (particularly changing temperatures) as these changes could then be made ‘outside’ of modelling space meaning the environmentally affected variables could be retained as constants. For systems that change over time a sequence of calculations will be needed to represent the system, however for continuous systems (such as water-based sewerage systems) a single calculation may adequately represent system performance – even though the detail may change in space.
- As hierarchy levels increase, the context widens and more parameters are involved. The proportion of the full system complexity represented by any particular parameter will decrease. A consequence of this is that the stripping of lower hierarchy parameters (which represent a diminishing proportion of the full system complexity) becomes a useful attribute by which the consequences of the parameter are retained without needing to have the parameter in the model. By residing in the context, then changing the context determines whether a parameter needs to be explicitly included in a model, or retained in the context.

To ensure that all the processes are fully represented in the model structure at each hierarchical level, it is sufficient to use only input parameters that are demonstrably seamless to the lowest hierarchical level. This may mean a long train of events are included, for example, aerobic proportion in a composting pile insists on a diverse range of input parameters including: particle characteristics, free air space, moisture content etc in addition to the effect of technology design at the pile boundary.

The use of seamlessness, information carrying structures, and identifying constraints within a series of hierarchies, combined with the intention of locating the Medawar zone rather than the ‘perfect’ solution would appear to be useful attributes to designing bottom-up models.

6 Discussion

It is argued here that the use of hierarchies places the contexts from all lower level hierarchies into the context of the particular hierarchy level being considered. Context can be seen as encapsulating those elements that are outside of the *immediate* modelling domain yet intimately relevant to it. Thus, laboratory studies in compost science are generally done in the context of constant environmental conditions, known oxygen concentration etc. They would probably be called assumptions in this context.

Hierarchies place the complexity into layers, consequently context can also be thought of as in layers and we add or remove layers of context as necessary. Thus:

- At the lower layer, a composting particle will exist in a context that includes: temperature, oxygen concentration etc, at a specific location in the *pile*.
- Over this is that a composting pile will exist in a *technological* context, where the technology will determine many of the state variables (such as temperature, aeration, particle mixtures etc).
- While all technologies are overlaid by the social domain; the technology will exist in the *social/institutional* context.

Lower layers of context are best for developing a rigorous argument, but they lose some of their applicability to the social context. Thus, when a laboratory study removes the social and technological contexts, the results are not valueless due to this removal, as the assumptions will apply to a specific social/technological context, even if this not made explicit. However, they will not necessarily be useful to other social/technological contexts. A model that embraced all social/technological contexts would be more useful.

Context therefore is a wider notion than assumptions and more useful when embracing the social domain. For example, a certain climate will be a characteristic of a community's location. This climate will have a range of temperatures (diurnal, seasonal, and weather related); consequently, the social context constrains the model in that it will need to accommodate changing temperatures if it is to be successful. Chapman (2008) argued that this limits the model to finite element methods. Any model which does not accommodate changing temperatures (or the effect of this on parameters which may normally be entered as constants) in its formulation will have limited application in the social context.

Through all these layers of context, this paper argues for the notion of seamlessness. Where seamlessness appears to be compromised (this being a potential constraint on our understanding), then the formation of information rich parameters can be used to 'carry' the fundamental laws and processes (the rigorous logic arguments that can be developed in the lower contexts) across the constraint. The ensuing information rich parameters (called computational units) 'carry' the fundamentals up to the technology scale and beyond. If this is done, then the potential for development of an 'efficient' technology is favoured. Efficient in this context would apply to as many elements as one includes in the model (cost and sustainability constraints are the two that this author would include).

The objectivity inherent in parameters that are based on the notion of seamlessness provides an alternative information carrier to the human one for judging a technology. It is an information carrier that is largely immune to political and commercial manipulation. In many respects, considering that this work extends the fundamental laws and processes (natural law) into our technology in an objective manner, then an element of this argument could be seen as allocating the *fundamental law* part of technology choice to its proper area, and removing it from the human/institutional frameworks. We cannot violate the laws of physics; consequently enabling their expression in any technology choice can only enhance the quality of the decision.

7 Conclusion

Context is a very useful thought process for anyone developing models as it contains all those explicit and implicit assumptions of the parameters that are used. However including the context of all the necessary parameters gets unwieldy when developing technologies as the complexity is too much. The use of hierarchies as a holder of the lower level contexts is possible and presents a form of simplification.

Hierarchies are a tool that can sit in the basket of tools until they are needed. Their value may reside more in that as on organisational tool in ecology they come from the real-world complexity and are used to hold the 'deeper' levels of the planet's complexity. In this location they potentially fill a useful bridging role.

8 Bibliography

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